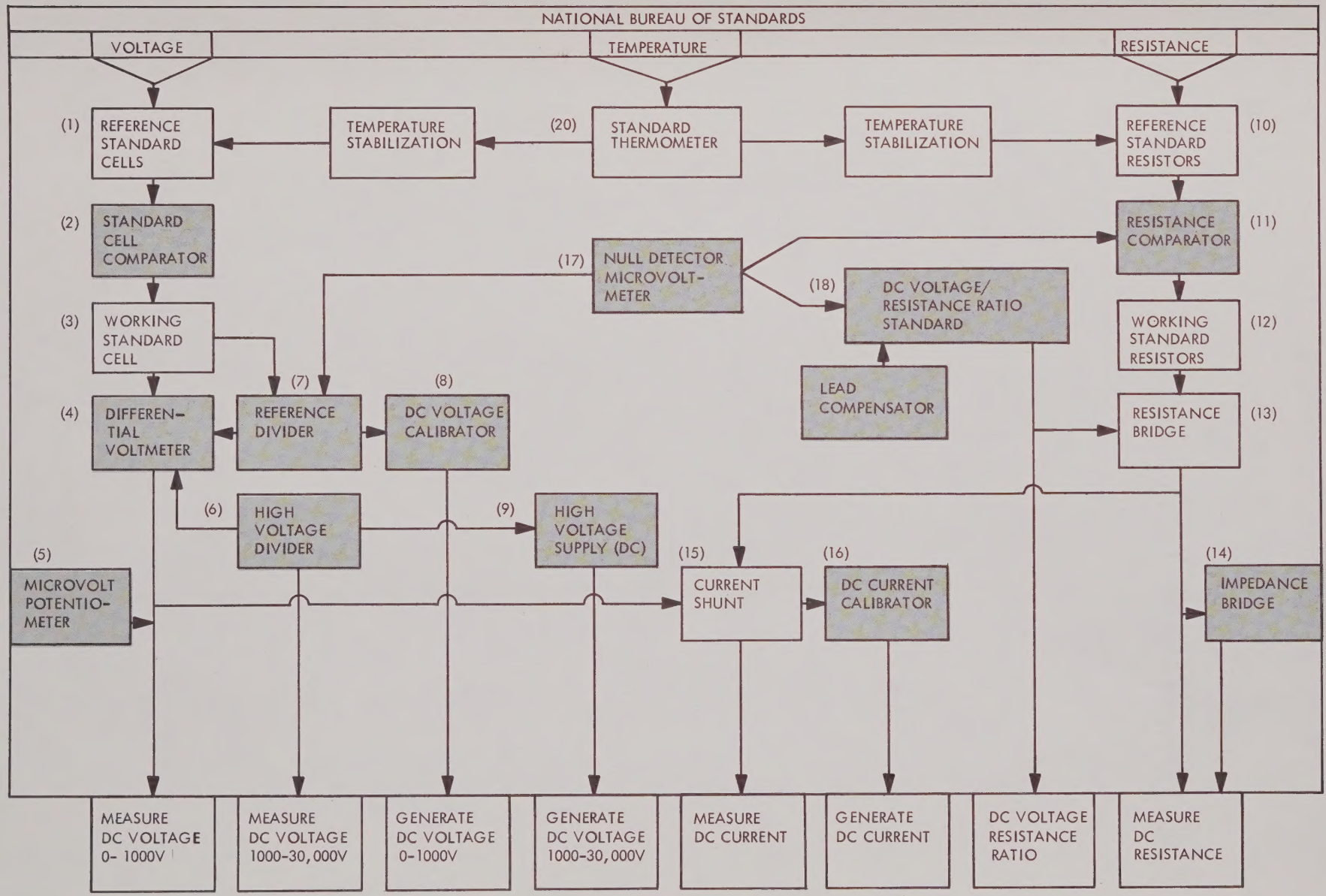
CALIBRATION TRACEABILITY CHARTS

JOHN FLUKE MFG. CO., INC.

P.O. Box 7428 Seattle, Washington 98133

DC VOLTAGE - CURRENT - RATIO AND RESISTANCE TRACEABILITY TO NBS



D. C. VOLTAGE, CURRENT, RATIO, AND RESISTANCE TRACEABILITY TO NBS

D. C. VOLTAGE

(1) Saturated standard cells (at least 3) in constant temperature enclosure. These must be periodically calibrated by NBS.
(2) The following Fluke instruments may be used to compare standard cells with 1-5 ppm resolution. Voltmeters: 895A, 885A, 881A. Microvolt Potentiometer: 831A.
(3) Working (unsaturated) standard cells are used for routine lab use protecting the reference cells from accidental abuse.
(4) A D. C. Differential Voltmeter provides wide range D. C. voltage measurement capability from 0 to ±1100 volts. Fluke Voltmeters: 895A, 885A, 881A, 871A depending on overall accuracy requirements.
(5) A constant resistance (Lindeck type) potentiometer provides measurement capability at low voltage levels. Fluke 831A Microvolt Potentiometer.
(6) A resistive voltage divider extends the measuring range of the D. C. differential voltmeter up to 30 kv. Fluke dividers: (depending on maximum voltage requirements) 80E-5, 80E-10, 80D-30.
(7) Certain fixed reference voltages up to 1100V may be compared directly to a standard cell using a resistive ratio divider --- Fluke 750A. Reference divider.
(8) A stable voltage supply with calibrated output is required which can supply current to test instruments without affecting output accuracy. Fluke 332A (0-1111 volts, 50 ma), 313A (0-50 volts, 0-2 amps).
(9) Same as (8) from 1000 - 30,000 volts.

D. C. RESISTANCE

(10) Three or more precision standard resistors provide reference for resistance measurements. These must be periodically calibrated by NBS.
(11) A means for comparing resistance ratios is required to calibrate working resistance standards in terms of reference resistors. Fluke 720A Kelvin-Varley Divider and 721A Lead Compensator.
(12) Working standard resistors are same or similar to reference standards but are intended for routine use.
(13) One or more resistance bridges may be used for 2 terminal and 4 terminal resistance measurements.
(14) General purpose impedance bridge may be used for lower accuracy resistance measurements --- Fluke 710B Impedance Bridge.

D. C. CURRENT

(15) Four terminal resistance standards (current shunts) may be used with differential voltmeter (item 4) to provide current measuring capability.
(16) Calibrated D. C. current source provides constant current output into a varying load resistance --- Fluke 382A (0-2A, 0-50V.)

D. C. NULL DETECTOR

(17) A null detector is required in the operation of items 7, 11, 13, 18 & 19. Fluke 845A, AB, or AR High Impedance Voltmeter/Null Detector provides 1 uv full-scale sensitivity with 10 megohm input resistance.

D. C. RATIO

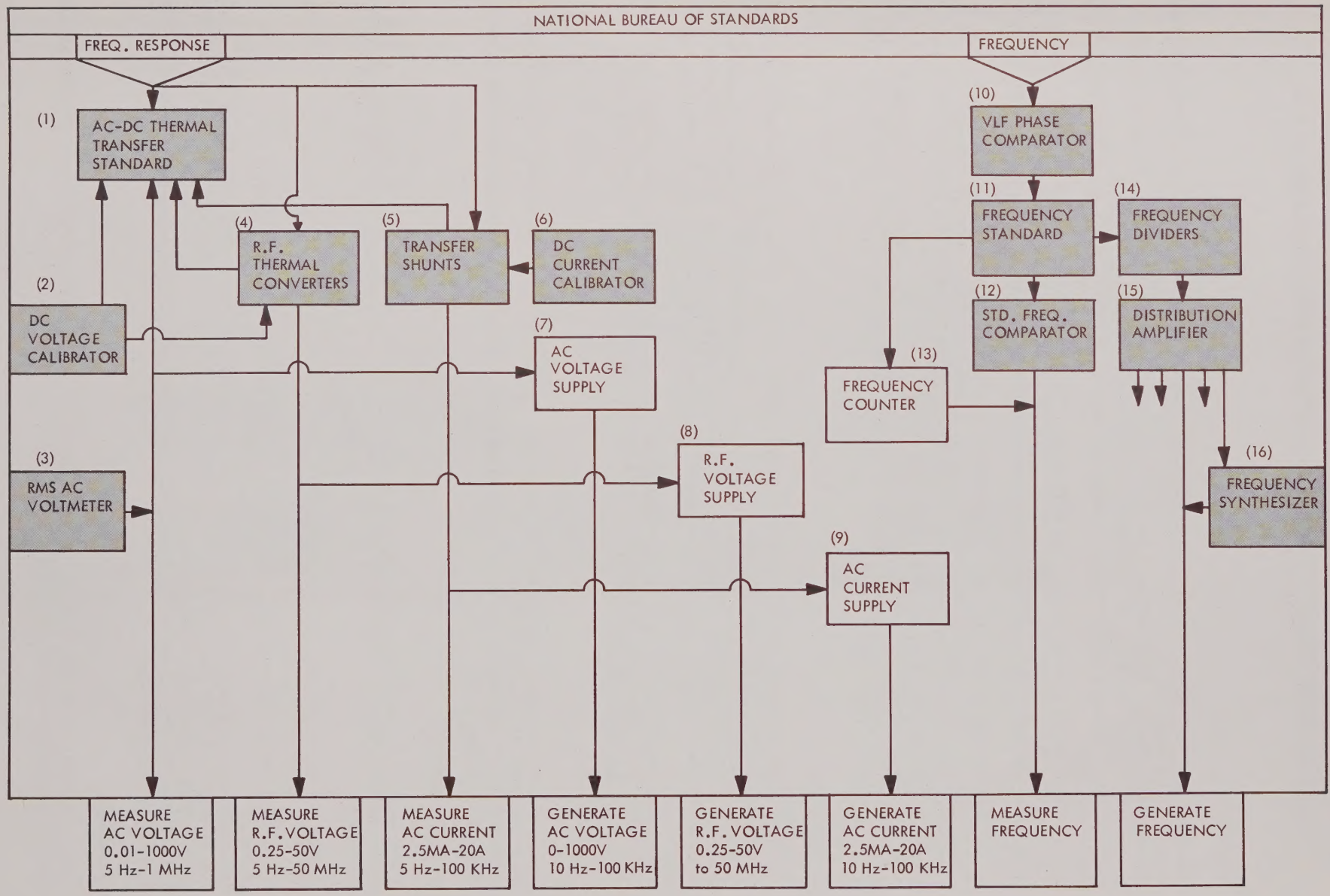
No direct traceability to NBS required. Ratios may be established and verified locally.

(18) D. C. voltage/resistance ratio standard provides partial calibration capability for items 4, 6, 7, 12, 13, & 14 in addition to many instruments in work load of laboratory. --- Fluke 720A Kelvin-Varley Divider (self-calibrating) or Fluke 725A.
(19) Lead compensator is accessory for convenient measurements using Kelvin-Varley Dividers --- Fluke 721A Lead Compensator.

TEMPERATURE

(20) NBS traceability (commonly through platinum resistance thermometer) required for ultimate accuracy in maintenance of saturated standard cells and reference standard resistors.

AC VOLTAGE - CURRENT AND FREQUENCY TRACEABILITY TO NBS



A. C. VOLTAGE, CURRENT, AND FREQUENCY TRACEABILITY TO NBS

A. C. (& R. F.) VOLTAGE AND CURRENT

(1) A thermal transfer standard relates rms A. C. voltages to D. C. voltage standards. NBS calibration of frequency response (AC-DC difference) required. Fluke 540B.

(2) A D. C. voltage calibrator is required as a standard for AC-DC comparisons. Fluke 332A, 313A--- (see item 8 under D. C. traceability).

(3) High accuracy A. C. voltage measurements may be made quickly and easily using an electronic A. C. voltmeter. --- Fluke 931A True RMS Voltmeter, 887A, 883A, 873A.

(4) High frequency thermal converters allow transfer measurements of R. F. voltages. Fluke A-55 R. F. converters (may be used with Fluke 540B or 550A). NBS calibration of frequency response required for traceability.

(5) Current shunts may be used with a voltage transfer standard for AC-DC transfer measurements of current. Fluke A-40 Current Shunts. NBS calibration of frequency response required for traceability.

(6) A D. C. current calibrator is required as a standard for AC-DC current comparisons. Fluke 382A --- (see item 16 under D. C. traceability)

(7) A stable A. C. voltage source with low distortion is required for calibration of all types of A. C. voltmeters. Item (1) or (3) may be used to determine output level.

(8) A stable R. F. voltage source is required for R. F. voltmeter calibration. Items (4) and (1) provide calibration of output level.

(9) A constant current AC source is required for A. C. ammeter calibration. Items (5) and (1) provide calibration of output current.

FREQUENCY

(10) A VLF receiver may be used to monitor NBS standard frequency transmissions. A phase comparison capability allows comparison of laboratory standard to the transmitted carrier frequency. --- Montronics 207-1.

(11) A stable oscillator provides a standard frequency reference for lab use. Internal standard available in Montronics 207-4 or 207-5 VLF Receiver/Comparator.

(12) A frequency comparator measures the frequency difference between laboratory standard and test signal at same nominal frequency. --- Montronics 100.

(13) A frequency counter referenced to item (11) above provides measurement capability at frequencies other than the standard.

(14) A frequency divider provides sub-multiples of the standard frequency for counter references, timing, etc. --- May be provided as option in Montronics 203 Distribution Amplifier.

(15) Distribution amplifier provides isolation and power to allow transmission of frequency standard signal to distant sites. Montronics 203.

(16) Synthesizer references fixed standard frequency input and provides wide range of output frequencies with high accuracy. Montronics 302A, 303A, 304A.

Fluke calibration systems are designed to provide the maximum calibration capability and flexibility for a standards laboratory while requiring a minimum of support equipment for maintenance.

The following series of diagrams indicate how such a system is designed.

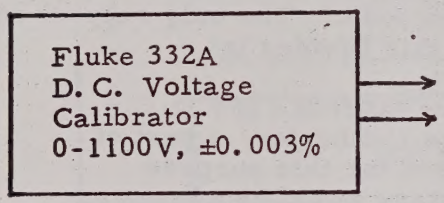


Fig. 1

Support equipment required for periodic calibration of 332A includes Fluke 885A Differential Voltmeter and a bank of standard cells with calibration traceable to NBS.

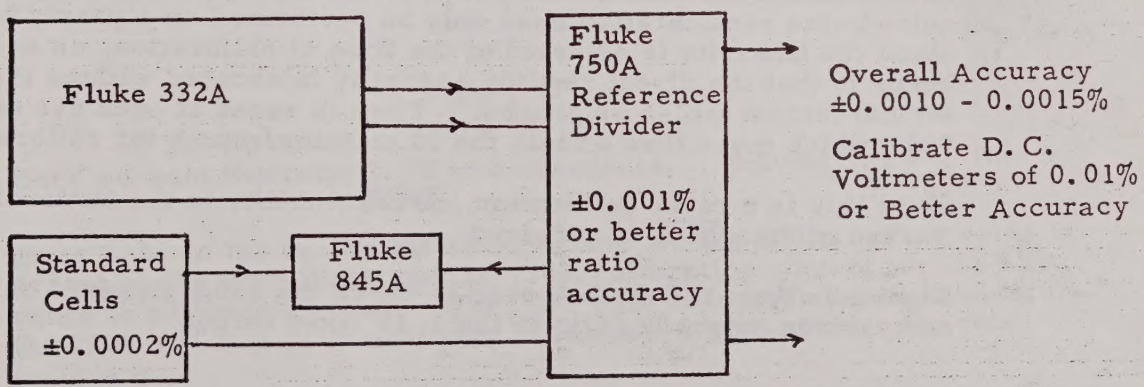


Fig. 2

In this system the accuracy has been increased by 2 to 3 times over the 332A alone but we have added the 750A Reference Divider and an electronic null detector (Fluke 845A). The standard cell bank was already required for maintenance of the 332A.

Support equipment required to maintain calibration of the 750A includes Fluke Model 720A Kelvin-Varley Divider and it's companion accessory, the Model 721A Lead Compensator. The 720A and 332A may also be used for the relatively simple calibration of the 845A Microvoltmeter.

The next obvious question is: How much equipment is required to maintain the 720A Kelvin-Varley Divider, etc?

We shall describe briefly the calibration of the 720A and subsequently, how it is used for 750A calibration, etc.

Since a Kelvin-Varley Divider is a ratio device, it can be calibrated by measuring the ratio relationships of the many equal valued resistors which make up the several decades. In the 720A, a Wheatstone Bridge has been built in for this purpose. The only support equipment required, then, for calibration of this Divider is:

1. A bridge voltage source (approx. 20V D. C.) The 332A D. C. Voltage Calibrator, a part of the system, may be used for this purpose although a dry cell battery would be adequate.

2. A bridge null detector with fairly high input resistance and 0.5 microvolt resolution. (The Fluke 845A, already a part of the system, is more than adequate for this requirement).

The calibration and adjustment of the 720A to within 0.1 ppm linearity is easily accomplished in 20 to 30 minutes and will be required only once a month for ultimate accuracy. If only 1 ppm linearity is required, the recalibration need only be performed on a yearly basis. Since the linearity is adjusted at the time of calibration, an additional bonus is that the direct reading accuracy is secured without the need for correction tables or graphs. Time is saved at each use of the 720A which more than offsets the 30 minutes/month for calibration.

Since this is a ratio calibration, no traceability to the National Bureau of Standards is required.

Figure 3 shows the method used to check the 750A standard cell comparison output in ratio to the 1.1V fixed output

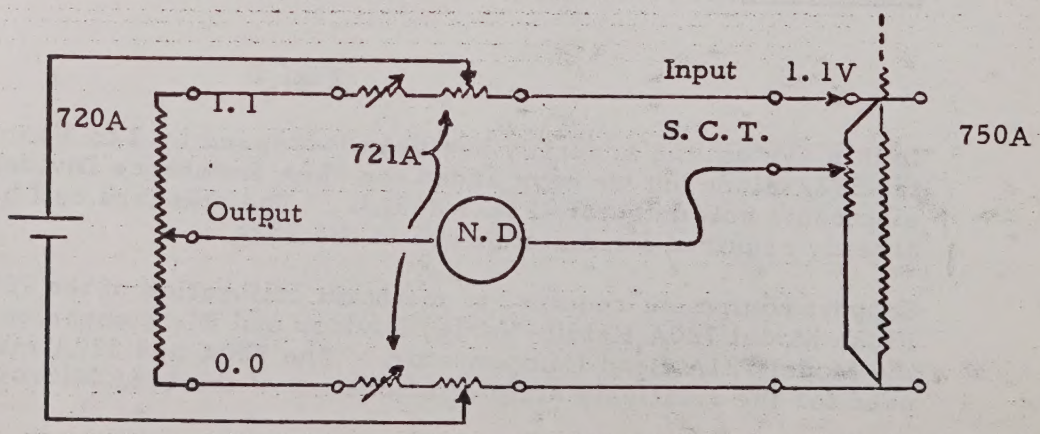


Figure 3.

Because of the 1.1 ratio input provided in the 720A K.V.D., the calibration shown in Figure 3 is direct reading.

Figure 4 shows how the 1.1V tap is now used as a reference for calibration (and adjustment) of the 5V range of the 750A.

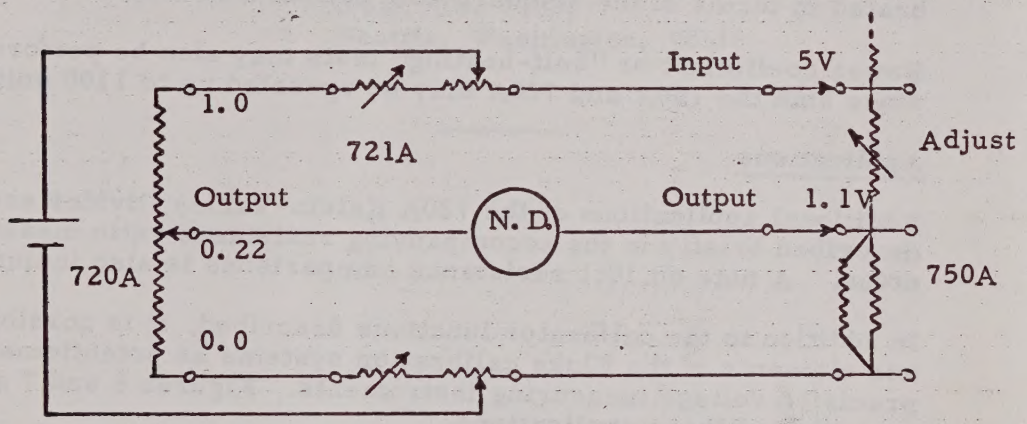


Figure 4.

Here we want the ratio $\frac{1.1V}{5.0V}$ to be accurate, Solving $\frac{1.1}{5} = \frac{x}{1.0}$ for x gives 0.22 as the equivalent ratio setting for the 720A. This value is preset on the 720A dials and the 750A calibration control for the 5V range is adjusted for null. The "0.1 ppm of input" specification of the 720A yields a ratio accuracy of about 0.5 ppm of ratio for this calibration.

Figure 5 shows the next step in this calibration sequence:

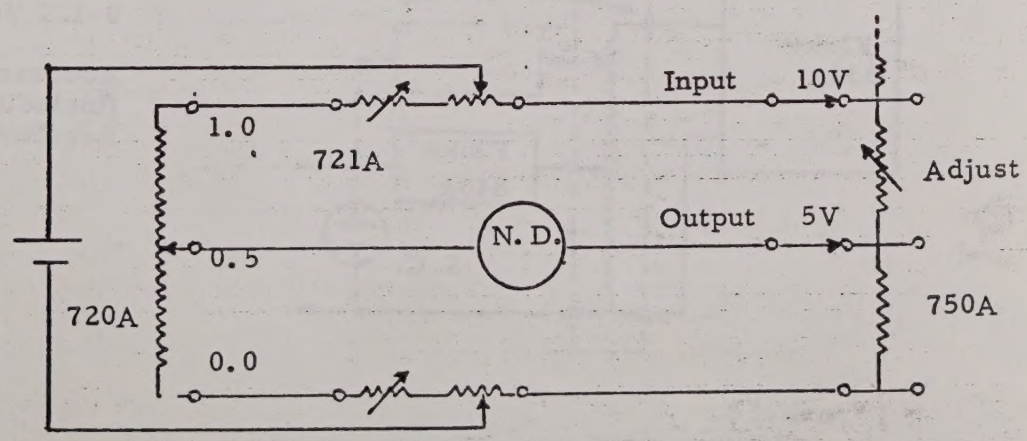


Figure 5.

As before, we compute the desired ratio $\frac{5.0V}{10.0V} = \frac{x}{1.0}$, $x = 0.5$

Preset 720A and adjust 750A 10V cal. for null.

The 0.1 ppm linearity of the 720A allows an accuracy of 0.2 ppm for this ratio calibration.

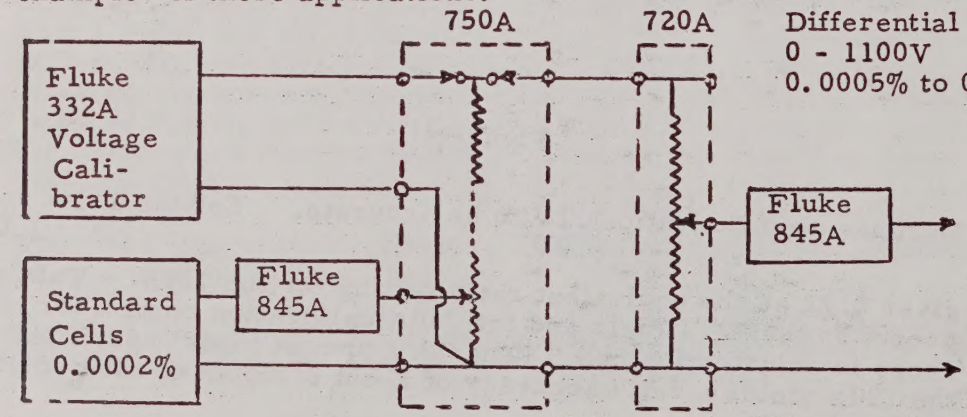
In the above manner, all ranges of the 750A up to 1100V are calibrated in terms of the standard cell comparison output.

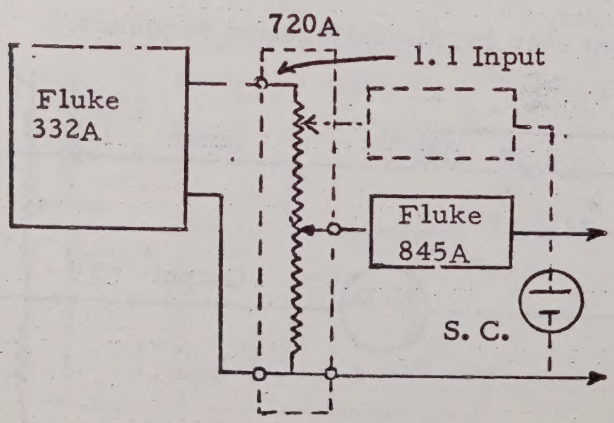
Power coefficient or "self-heating" tests may also be performed since both the 750A and 720A may be operated up to 1100 volts.

Applications

Additional applications of the 720A Kelvin-Varley Divider are described briefly in the accompanying resistance ratio measurement notes. A note on 10:1 resistance comparisons is also included.

In addition to the calibrator functions described, it is possible to use elements of the Fluke calibration systems as potentiometers and precision voltage measuring instruments. Figures 6 and 7 show examples of these applications.





Potentiometer
0-1.1 Volts

Accuracy: 0.0003%
(Including Standard Cell)
Resolution: 0.1 Microvolt

RESISTANCE RATIO MEASUREMENT NOTES

By

Charles B. Newcombe
John Fluke Mfg. Co. Inc.,
P.O. Box 7428,
Seattle, Washington, 98133

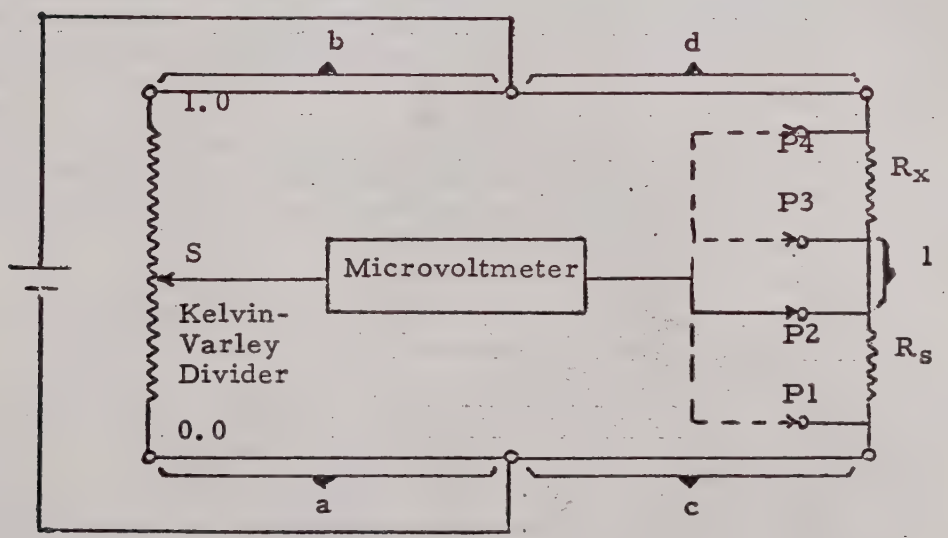
RESISTANCE RATIO MEASUREMENT NOTES

Introduction

Modern Kelvin-Varley Dividers may be used to perform a variety of ratio measurements with increased resolution and accuracy over previous techniques. Three basic methods will be discussed, and applications of each presented.

Resistance Comparison

Figure 1 shows the basic resistance comparison setup. The readings S1 through S4 are taken with the microvoltmeter connected to P1 thru P4, respectively. This measurement is a "four-terminal" comparison of R_s and R_x. The relation, $R_x = R_s$ (S4 - S3) / (S2 - S1), discounts the resistances a, b, c, d, and 1 (provided they remain constant while the four measurements are made). Only the linearity of the divider must be known to accurately determine the ratio, (S4 - S3) / (S2 - S1). The absolute value of R_s must, of course, be known to arrive at a value for R_x.



$$\frac{R_x'}{(S4 - S3)} = \frac{R_s}{(S2 - S1)} \quad \text{or} \quad R_x = R_s \frac{(S4 - S3)}{(S2 - S1)}$$

Figure 1.

Voltage Divider Comparison

Figure 2 shows the setup used for voltage divider calibration. The addition of the end resistance balance feature requires the performance of the following preliminary procedure:

a. With S and K set at 0.0, the Low Balance controls are adjusted for microvoltmeter "null".

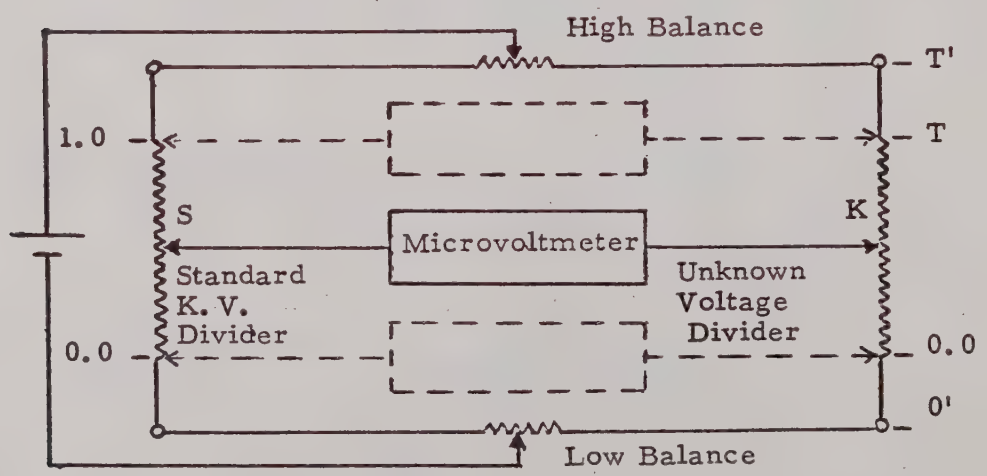
b. With S set at 1.0 and K set at T, the High Balance controls are adjusted for null.

c. Steps a and b are repeated until no further adjustment is required.

This procedure allows the operator to measure the absolute linearity of the unknown divider in terms of the absolute linearity of the standard Kelvin-Varley Divider (KVD). The terminal linearity of the unknown divider may be measured by connecting the microvoltmeter to the input terminals 0' and T' for the end resistance balance procedure.

An absolute linearity calibration will never indicate an error for K = 0.0 or K = T by definition. A terminal linearity calibration will always indicate a ratio greater than 0.0 at K = 0.0 and some ratio slightly less than 1.0 at K = T.

It is readily seen that if the maximum setting T (of the unknown divider) is equal to 1.0 then the measuring system is "direct reading" and S should be numerically equal to K for all settings of K (at null).



After End Resistance Balance: $\frac{K}{T} = \frac{S}{1.0}$ or $K = ST$

Figure 2.

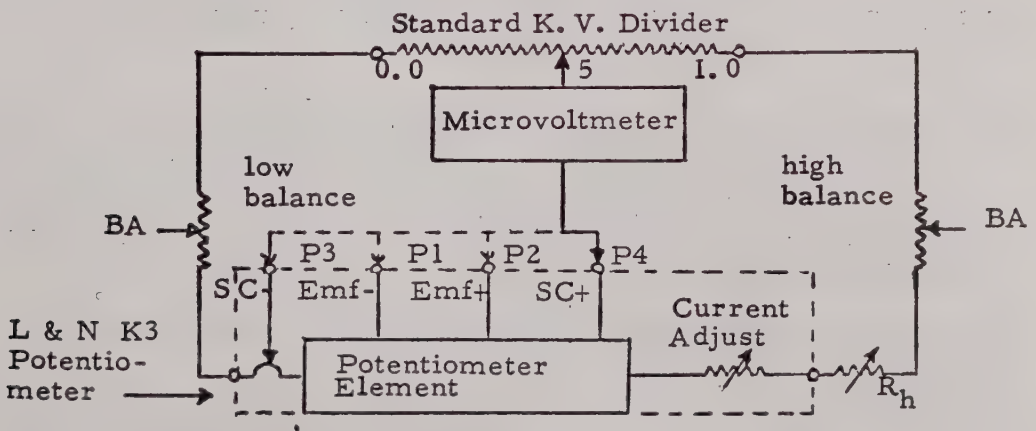
Potentiometer Calibration

Figure 3 makes use of principles discussed in the preceding paragraphs, but with the addition of R_h. Here we would like the difference (S2 - S1) to represent the setting of the potentiometer EMF dials directly. This is the same principal outlined in NBS Monograph 39 except that the Universal Ratio Set has been replaced by the standard KVD.

The low balance, R_h, and high balance controls are adjusted, in that order, until the difference (S4 - S3) is equal to 0.1 x (std. cell dial setting). The difference (S2 - S1) will then represent 0.1 x (EMF dial setting), and the KVD is "direct reading" in that a change in ratio of 0.1 represents a 1 volt setting on the potentiometer.

Using a 7 dial KVD adjusted within 0.1 ppm of full scale measurements may be made with uncertainties less than 3 microvolts relative to the potentiometer settings. This accuracy is more than adequate for the calibration of the X1 range linearity of the Leeds and Northrup K-3 potentiometer used as an example in Figure 3. A resolution problem arises when attempting to measure the range factors for the X0.1 and X0.01 ranges. This problem is minimized by reducing R_h and the potentiometer current adjust resistances to minimum, losing the direct reading feature but increasing resolution by a factor of 4. This is adequate, however, accuracy is further improved since the first decade of the KVD is not moved during the measurement of (S2 - S1) on the X0.01 range and KVD uncertainties are then reduced to less than ±0.04 ppm of full scale.

The formulas for computing range factors are given in Figure 3.



$\Delta E = (S_2 - S_1)$, $\Delta S = (S_4 - S_3)$

Range Factor Computation: (F x Nominal Range Factor)

$$F_{(0.1)} = \frac{\Delta S_{1.0}}{\Delta E_{1.0}} \times \frac{\Delta E_{0.1}}{\Delta S_{0.1}} \qquad F_{(0.01)} = \frac{\Delta S_{1.0}}{\Delta E_{1.0}} \times \frac{\Delta E_{0.01}}{\Delta S_{0.01}}$$

Figure 3.

Applications

Resistance comparisons using the Kelvin-Varley Divider are practical only when resistance ratios other than 1:1 or 10:1 are involved. This is true because 4 separate measurements and several computations must be performed for each comparison, and direct reading resistance measuring systems are generally available with 1:1 and 10:1 capabilities. The residual resistance a, b, c, d, and 1 (of Figure 1) may be disregarded if the resistances being compared are high and terminal linearity corrections are available for the KVD. In this instance only one measurement is necessary and the balance equation is:

$$\frac{R_x}{R_s} = \frac{(1-S)}{S} \quad \text{or} \quad R_x = \frac{R_s(1-S)}{S}$$

This solution may also be written:

$$R_x = \frac{R_s}{S} - R_s$$

This form is more convenient where the ratio R_s/R_x is less than 0.01 and R_s is decimal multiple of 1 ohm (1 megohm for example).

The basic calibration of the standard KVD should be in terms of its absolute linearity. This calibration may be used for virtually all measurements excepting only the simplified resistance comparison discussed above. In the case of the voltage divider comparison, the end resistance may be balanced to measure either the absolute or terminal linearity of the unknown divider, but both instances use the 0.0 and 1.0 settings of S as reference.

This ratio calibration system may be used to calibrate the Kelvin-Varley Dividers, put-and-take dividers (such as the Universal Ratio Set), voltboxes, and voltage calibrators. Voltbox calibration is limited by the maximum voltage specification of the standard KVD but the ratios may be determined at low voltages and heating effects tested by other means.

The ratios measured for voltbox calibration would be as follows:

$\frac{3.0V}{1.5V}, \frac{7.5}{3.0}, \frac{15}{7.5}$ etc. The 1.5V tap is assumed perfect and the actual value of the 3.0V tap is computed. This value is used to determine the value of the 7.5V tap and so forth. Extreme caution must be exercised to be sure that the value computed from one measurement is the true value of that portion of the circuit appearing in the next measurement. Lead residuals, though small, may cause a large divergence from true ratio by the time the 1500V ratio is computed.

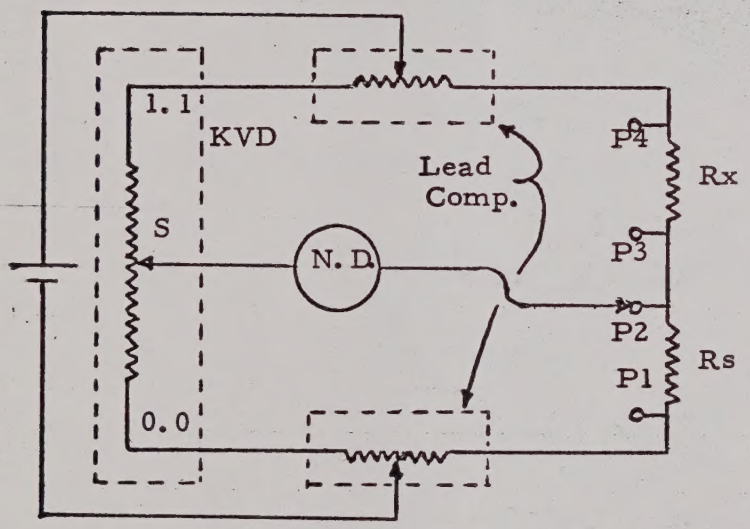
The application under Potentiometer Calibration is obvious. Several different varieties of potentiometer exist, some using 2 volt sources, some using 6 volt sources, etc. R_h is needed to accomodate all of these up to a source voltage of 10 volts while maintaining the direct reading feature.

10:1 RESISTANCE COMPARISONS USING KELVIN-VARLEY DIVIDER WITH 1.1 RATIO INPUT

Charles B. Newcombe
John Fluke Mfg. Co. Inc.
P.O. Box 7428
Seattle, Washington, 98133

10:1 RESISTANCE COMPARISONS USING KELVIN-VARLEY DIVIDER WITH 1.1 RATIO INPUT

Fig. 1 Comparison Circuit for Resistors where Rx = 10Rs within 0.1%



Conditions:

1. Rx = 10 Rs ±0.1%
2. P4 Balanced to KVD 1.1 Output with Lead Comp.
3. P1 Balanced to KVD 0.0 Output with Lead Comp.
4. $\Delta S = (S - 0.10000)$

Referring to Fig. 1

$$\frac{Rx}{Rs} = \frac{1.1 - (0.1 + \Delta S)}{0.1 + \Delta S} \quad \text{Then}$$

$$Rx = \left(\frac{1.0 - \Delta S}{0.1 + \Delta S} \right) Rs$$

Evaluation of $\left(\frac{1.0 - \Delta S}{0.1 + \Delta S} \right)$ Term letting A = 0.1, B = ΔS, C = 1.0

Then Term becomes $\left(\frac{C - B}{A + B} \right)$ By long division the quotient is

$$\frac{C}{A} - \frac{B}{A} - \frac{BC}{A^2} + \left(\frac{\frac{B^2}{A} + \frac{B^2 C}{A^2}}{A + B} \right)$$

Disregarding the term in ( ) will contribute less than 1 ppm error to measurements where ΔS is less than 0.0001000. If ΔS is less than 0.0000100 then the error is less than 0.01 ppm.

Substituting Back: $\frac{C}{A} - \frac{B}{A} - \frac{BC}{A^2}$ Becomes $\frac{1.0}{0.1} - \frac{\Delta S}{0.1} - \frac{\Delta S}{0.01}$

This reduces to 10 (1-11 ΔS).

Thus Rx = 10 (1-11 ΔS) Rs.

Example: Ratio reads 0.1000100, $\Delta S = 0.000010$

Rs = 10.00000 Ohms Then Rx= 10(999890)Rs

or Rx = 100(.999890) = 99.9890 Ohms

If ratio difference $S_3 - S_2$ is larger than 2 or 3 ppm, then the following S reading at S_2 should be adjusted as follows:

$$S_2 + \frac{(S_3 - S_2)}{11} = S$$

In this manner 4 terminal, 10=1 resistance comparisons may be performed.

If KVD is spec'd at ±0.1 ppm of full scale then the comparison may be made to 1.0 ppm accuracy.